Turbulent Microstructure Studies in Coastal Ocean Boundary Layers

Neil S. Oakey
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
Canada B2Y 4A2
Phone: (902) 426-3147 fax: (902) 426-7827 e-mail: oakeyn@mar.dfo-mpo.gc.ca

Award #: N00014-95-1-1030
http://www.mar.dfo-mpo.gc.ca/science/ocean/epsonde/welcome.html

LONG-TERM GOALS

My long term goal in this study is to obtain an extensive picture of turbulent mixing processes from near surface to near the bottom boundary layer at dissipation scales in conjunction with measurements of mixing from the injection of a tracer (Ledwell) and in the context of larger scale measurements in the Coastal Mixing and Optics study.

OBJECTIVES

I wish to establish whether the diapycnal mixing rates inferred from turbulence measurements agree with those determined from the dispersion of a tracer. This year, temperature microstructure and dissipation data from the two field experiments of 1996 and 1997 were analyzed using various ensemble-averaging techniques to obtain vertical diffusivities. This will allow me to make a clearer comparison of vertical diffusivities determined from microstructure to that determined from the tracer.

APPROACH

I participated in a joint study with Jim Ledwell (WHOI) in two field experiments at the Coastal Mixing and Optics experimental site. Microstructure measurements were obtained using the vertical profiling instrument EPSONDE in repeated profiles from the surface to near the bottom at a time of weak stratification after the passage of a hurricane (1996) and of late summer stronger stratification (1997). The strategy was for Ledwell to inject a tracer on a specific density level and to map the area to obtain the initial conditions for the tracer. This was followed by a microstructure survey along the predicted track of the tracer as it advected with the measured currents. Tracer and microstructure surveys were interspersed over several days to follow the evolution of the dye.

WORK COMPLETED

The measurement of microstructure profiles, interspersed with dye injection and dispersion measurements were completed for four depths and density gradients from two field programs in 1996 and 1997 done near the Coastal Mixing and Optics mooring site in about 70 meters of water. Two dye-microstructure studies completed by Ledwell and Oakey in the fall of 1996 were with rhodamine at mid-depth and fluorescein at about 50 meters. In 1997 injections were done at about 20 meters from the surface with rhodamine and at about 5 meters above bottom with fluorescein near the central mooring site of the Coastal Mixing and Optics experiment in water depth of about 70 meters. In excess of 2000 microstructure profiles have been analyzed and edited to obtain estimates of dissipation, e , and temperature variance, c_q , and derived vertical diffusivities for each profile segmented in bins of about 1.8 meters from commonly used microstructure models. Estimates of vertical diffusivity from microstructure data were analyzed using various ensemble-averaging techniques to obtain vertical diffusivities and have been compared to those obtained from Ledwell's dye dispersion data. These results have been presented at meetings and papers are in preparation for publication.

RESULTS

Microstructure data from all four dye-microstructure experiments have been analyzed and edited to provide estimates of the rate of turbulent mixing to compare with the estimates of mixing from the spreading of a tracer. As an example of the results, data from dye injection 2 (1996) at a depth of 45 meters ($s_q = 24.3$) is shown in the composite Figure 1. Dye injected at day 256.2 moved westerly along the shelf, where the solid line indicates the path of the center of the tracer patch projected between the surveys using hourly ADCP velocities. Events in the dye experiment include the dye injection and three surveys as well as sets of microstructure data that were collected along three lines. The CMO mooring sites are indicated by the filled circles.

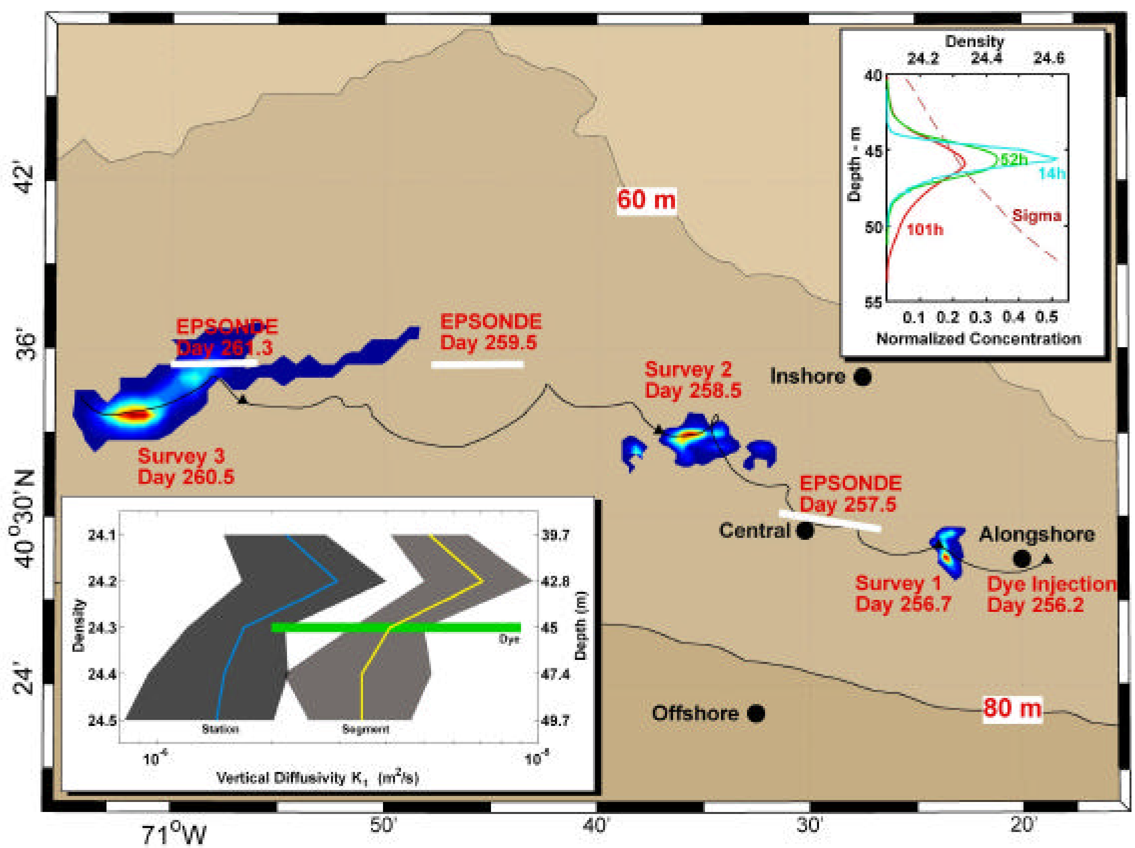

Figure 1: Microstructure and tracer measurements for the fluorescein dye injection in on day 256.2 of 1996 at a depth of 45 meters and a density of 24.3.

The microstructure data were obtained in bursts of typically 20 to 30 profiles by successively dropping the instrument EPSONDE along a line of about 5-km as the ship steamed at about 2 knots. A total of over 500 profiles were acquired in 56 hours of sampling at the three sites shown in Figure 1 as broad white bars (centered at day 257.5, 259.5 and 261.3). These microstructure measurements were closely correlated in space and time with the dye measurements. Vertical diffusivities of heat, K_T, and mass, K_ρ, were estimated from the temperature gradient microstructure and the turbulent dissipation, respectively. Combining dissipation with mean velocity shear measured with an ADCP allowed one to estimate the vertical diffusivity of momentum, K_M. Different techniques of obtaining an *ensemble average* from the microstructure results were used to compare microstructure estimates to those from the dye. As an example, vertical diffusivity K_T is shown in the inset in Figure 1. The yellow profile with light gray error bars was obtained by averaging the vertical diffusivities for every 1.6-meter vertical *segment* of data. The blue curve with its dark gray error bars was obtained by averaging the temperature variance and mean gradient separately for each 15 to 20 profiles acquired in one transit of a site line (a *station*) and then dividing to obtain vertical diffusivity.

The diffusivity from the dye calculated from the increase of the second moment of the dye distribution shown in the upper right inset yields the vertical diffusivity shown as a green bar (indicating the errors) in the lower left inset overlaid on the estimates of vertical diffusivity from microstructure measurements. These two techniques yield similar estimates of vertical diffusivity. In general, the dye and microstructure results from all four experiments agreed in that they provided the same mixing rates within the errors of the measurements. The caveat is that the error bars are large - typically at least a factor two for each type of measurement.

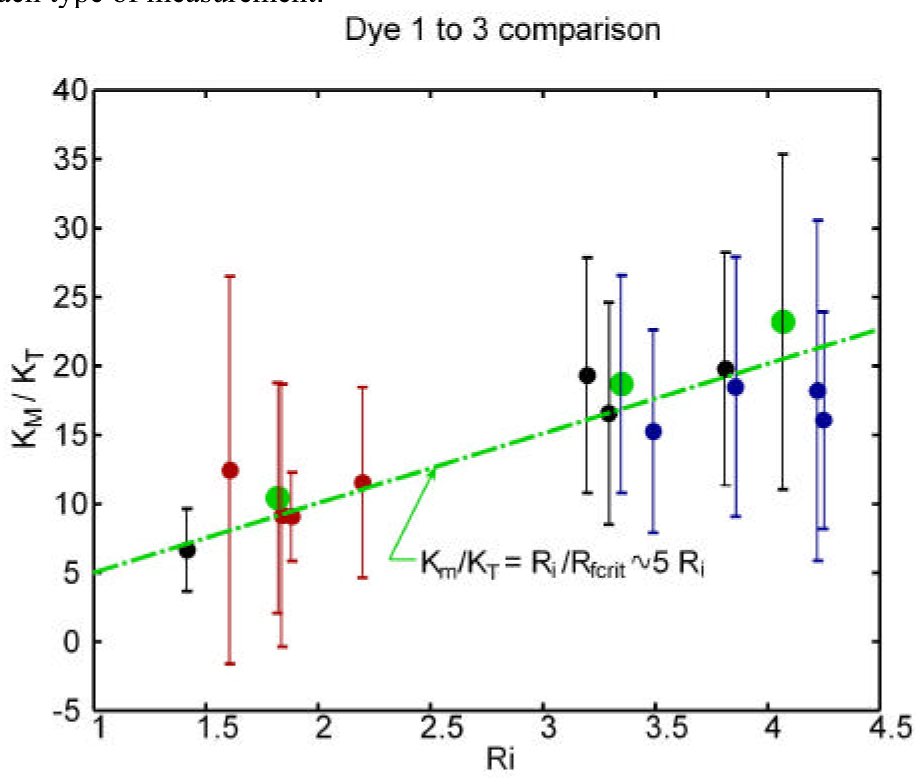

Figure 2: The ratio of vertical diffusivity of momentum and heat is plotted versus the Gradient Richardson Number. The large green point is the target surface value. Colors identify the three experiments: red – dye 1, blue – dye 2, black – dye 3. The dashed line represents the ratio R_i/R_{fcrit} □ $5R_I$ where R_{fcrit} is approximately 0.2.

The ratio of the vertical diffusivity of momentum to the vertical diffusivity of heat is compared to the Gradient Richardson Number, R_i , in Figure 2. Data were chosen for this plot as segments of data around the dye target isopycnal (indicated by the large Green dot). The error bars represent the standard error of the mean estimated from a bootstrap technique. The data are consistent with the green dashed line which represents the ratio of R_i / R_{fcrit} where R_f is the Flux Richardson Number.

IMPACT/APPLICATIONS

This is the first time that tracer and microstructure measurements of mixing in the ocean have been done on the same length and time scales to test commonly used mixing models.

TRANSITIONS

RELATED PROJECTS

This study is part of the Coastal Mixing and Optics experiment in particular the turbulence results are being compared to those obtained by Jim Ledwell of WHOI.

REFERENCES

Sundermeyer, M. A., 1998: Studies of lateral dispersion in the ocean. Ph.D. thesis, Massachusetts Institute of Technology, 215 pp.

PUBLICATIONS

Greenan, B.J.W. and **N.S. Oakey**, 1999. A Tethered Free-Fall Glider to Measure Ocean Turbulence, Journal of Atmospheric and Oceanic Technology, 16, 1545-1555.

Oakey, N. S. and N.A. Cochrane, 1999. Turbulent Mixing in Solitons. The 1998 WHOI/IOS/ONR Internal Solitary Wave Workshop, Woods Hole Technical Report WHOI-99-7, 123-127.

Oakey, Neil S., 1999. Turbulence Dissipation Sensors. Submitted to Academic Press: Encyclopedia of Ocean Sciences, December 3, 1999.

Greenan, Blair J.W., **Neil S. Oakey,** F.W. Dobson, 2000, Estimates of Dissipation in the Ocean Mixed Layer Using a Quasi-Horizontal Microstructure Profiler, In Press, Journal of Physical Oceanography.